Transactions of the **13th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 13), Escola de Engenharia - Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, August 13-18, 1995

Fatigue strength of steel fiber reinforced concrete structures with notches

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ABSTRACT:Fatigue tests were performed in order to investigate the fatigue strength of SFRC(Steel Fiber Reinforced Concrete) structures. Twenty-four SFRC beams were used in the tests, relationship between loading and mid-span deflections, the number of repeated loading cycles when the first crack occurs of SFRC beams were observed under the fatigue loading. S-N curves were drawn to present the fatigue strength of SFRC beams. According to the regression technique, some empirical formulae for predicting the fatigue strength of SFRC beams with notches were also suggested.

1 INTRODUCTION

The mechanisms of fiber reinforced concrete was first studied by Romualdi and Batson(Romualdi 1963). They proposed that the increases in flexural strength and ductility of concrete with steel fibers can be attributed to the ability of the fiber to restrain cracks. Romualdi and Mandel showed that the first crack strength is dependent upon the spacing of fibers(Romualdi 1964). Hsu et al. showed that all concrete contains flaws which could increase in size under loads which were less than 50% of the ultimate loads(Hus 1963). Chang and Chai studied that the fatigue strength with 2,000,000 repeated loading cycles in SFRC beams with the steel fiber content varying 0.5, 1.0, 1.5% shows about 71.3, 74.4, 77.8% on the first crack static flexural strength, respectively(Chang 1991,1992,1993).

From the previous studies above, it can be concluded that the strength of SFRC beams is a function of the fiber content and the fiber aspect ratio. However, the effect of notch to depth ratios on the fatigue behavior of SFRC beams has not been clearly examined. On this basis, in this study, the fatigue strength of SFRC beams with different notch to depth ratios has been investigated.

2 TEST PROGRAM

Steel fibers with diameters of 0.6mm, and length of 60mm were used to reinforce the concrete beams. The material properties of steel fiber are shown in table 1. Portland cement was used and the maximum size of coarse aggregate was 19mm. The mix proportion used is shown in table 2(The minister of construction in korea 1988).

Table 1. Material properties of steel fiber.

Diameter (mm)	Length (mm)	Aspect ratio	Density (g/cm^3)	Young's modulus (GPa)	Tensile strength (MPa)
0.6	60	100	7.85	198	1275

Table 2. Mix proportion of concrete.

Max. size of coarse aggregate (mm)	Air content (%)	Water content (kg/m^3)	Cement content (kg/m^3)	Water/ cement ratio (%)	Fine aggregate content (kg/m^3)	Coarse aggregate content (kg/m^3)
19	2	185	482	38.4	752	936

2.1 Test specimens

Rectangular beams of 10×10×60cm were made, and the specimen series were classified according to the notch to depth ratios, 0.0, 0.2 and 0.4. The specimen series are shown in table 3.

Table 3. Specimen series.

Spcimen series	Fiber content (%)	Fiber aspect ratio	Notch to depth ratio	Static flexural strength (N)
A-series	1.5	100	0.0	9120
B-series	1.5	100	0.2	6227
C-series	1.5	100	0.4	4093

2.2 Test procedure

In the fatigue test, the three point bending test by the fatigue test machine was done. The minimum value of repeated loading was fixed at zero and the maximum value was different for each specimen in order to draw appropriate S-N curves. Ten load cycles at the beginning were repeated statically ranged from the minimum to the maximum load level. Then dynamic load cycles were applied to the specimens with the same magnitude at the rate of 600 cycles per minute.

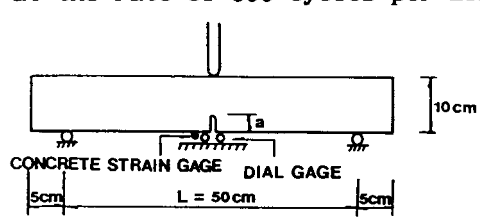

Figure 1. The general view of the fatigue test.

During the tests, the mid-span displacement were measured periodically, and the number of repeated loading cycles when the first crack occurs were detected. The general view of the fatigue test is shown in figure 1.

3 FATIGUE TEST RESULTS

Table 4 contains the maximum value of repeated loading, the first crack static flexural strength, and the number of repeated loading cycles when the first crack occurs.

Table 4. Fatigue test results.

Spec. No.	Pmax (N)	Pmax /Psi	Nu (N)	Spec. No.	Pmax (N)	Pmax /Psi	Nu (N)	Spec. No.	Pmax (N)	Pmax /Psi	Nu (N)
A-1	7752	0.85	132460	B-1	5293	0.85	97820	C-1	4168	0.85	60370
A-2	7752	0.85	176080	B-2	5293	0.85	145900	C-2	4168	0.85	85650
A-3	7296	0.80	397230	B-3	4982	0.80	259880	C-3	3922	0.80	165780
A-4	7296	0.80	423250	B-4	4982	0.80	285360	C-4	3922	0.80	196620
A-5	6840	0.75	797940	B-5	4670	0.75	449740	C-5	3677	0.75	259200
A-6	6840	0.75	904580	B-6	4670	0.75	576800	C-6	3677	0.75	278380
A-7	6384	0.70	1898820	B-7	4359	0.70	989290	C-7	3432	0.70	402690
A-8	6384	0.70	2000000	B-8	4359	0.70	1049630	C-8	3432	0.70	662590

Note: Pmax is the maximum value of repeated loading, Psi is the first crack static flexural strength, Nu is the number of repeated loading cycles when the first crack occurs.

3.1 Relationship between the repeated loading cycles and the compliance

The compliance calculated from the load-displacement curve on the repeated loading cycles, is studied in order to find the stiffness of SFRC beams under the fatigue loading with the changes of the notch to depth ratio. As shown in figure 2, by increasing the notch to depth ratio, the maximum displacement of SFRC beams under the fatigue loading increases. This phenomenon is true until the first crack occurrence, and the maximum displacement when the first crack occurs of the specimens with the notch to depth ratios of 0.2, 0.4 are increased about 6.6, 9.5 times, respectively, as compared with that under the static loading.

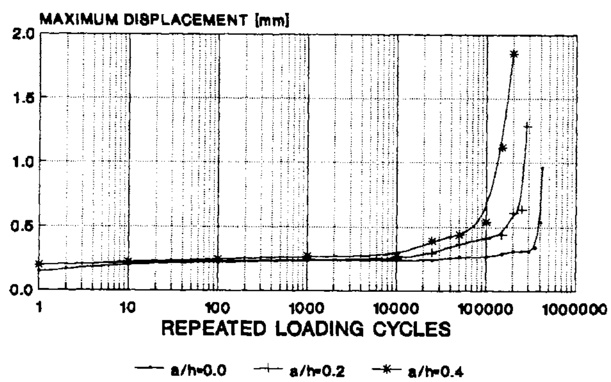

Figure 2. The relationship between the repeated loading cycles and the maximum displacement.

Figure 3 shows the relationship between the notch to depth ratio and the compliance. From this figure, by increasing the notch to depth ratio, the compliance until the first crack occurrence increases. From these results, it was found that the larger the notch to depth ratio are, the energy spent on crack growth of SFRC under the fatigue loading decreases.

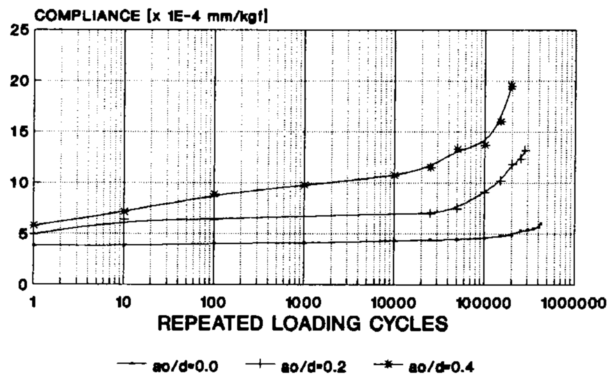

Figure 3. The relationship between the repeated loading cycles and the compliance.

3.2 Fatigue strength

The results of fatigue test are generally expressed in terms of S-N curves. If the S-N curve has an asymptotic line, the stress corresponding to this line is called the fatigue limit of the materials. Most metals have fatigue limits like this, but because concrete does not have a clear fatigue limit, the fatigue strength under a specified repeated loading cycle is used as the fatigue limit of the concrete(Norby 1958).

From the fatigue test, the relationship between the fatigue life and the fatigue strength could be expressed exponentially as follows:

$$R = K \cdot \exp(-C \cdot \log N) \qquad \cdots\cdots (1)$$

where K and C are the coefficients determined by a test. The above formula can be rewritten as follows:

$$\log R + C \cdot \log e \times \log N = \log K \qquad \cdots\cdots (2)$$

where

$$\log K = Y,\ \log R = \alpha,\ C \cdot \log e = \beta \qquad \cdots\cdots (3)$$

then the above equation can be rewritten as:

$$Y = \alpha + \beta \times \log N \qquad \cdots\cdots (4)$$

where Y is the fatigue strength, N is the fatigue life. From the test which was conducted in order to observe the fatigue life and the fatigue strength with the changes of the notch to depth ratio, the relationship between the fatigue life and the fatigue strength of SFRC beams could be drawn as shown in Figures 4, 5 and 6 by regression analysis, and the following formulae were obtained:

(1) when the notch to depth ratio is 0.0
$$Y = 155.804 - 13.609 \times \log N \qquad (5)$$

(2) when the notch to depth ratio is 0.2
$$Y = 165.806 - 15.891 \times \log N \qquad (6)$$

(3) when the notch to depth ratio is 0.4
$$Y = 167.649 - 16.965 \times \log N \qquad (7)$$

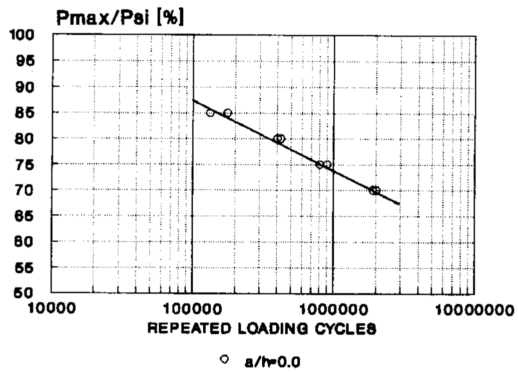

Figure 4. The relationship between the fatigue life and the fatigue strength of SFRC when the notch to depth ratio is 0.0.

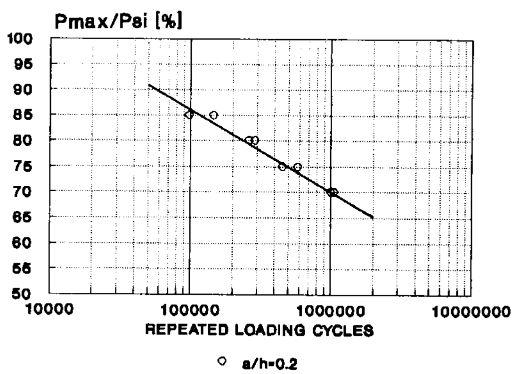

Figure 5. The relationship between the fatigue life and the fatigue strength of SFRC when the notch to depth ratio is 0.2.

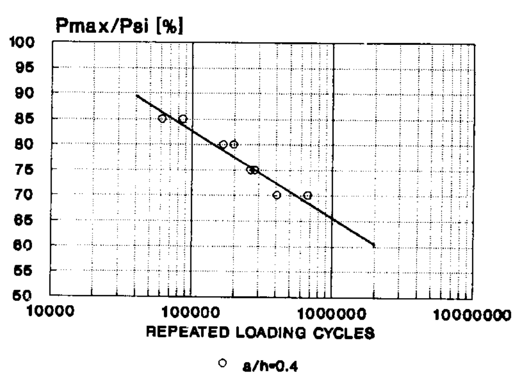

Figure 6. The relationship between the fatigue life and the fatigue strength of SFRC when the notch to depth ratio is 0.4.

According to the S-N curves drawn by the regression analysis on the fatigue test results, the fatigue strength to the first crack static flexural strength decreases by increasing the notch to depth ratio. The fatigue strength with 2,000,000 repeated loading cycles in SFRC beams with the notch to depth ratio varing 0.0, 0.2 and 0.4 shows about 70.1, 65.7 and 60.8% to the first crack static flexural strength, respectively.

4 CONCLUSIONS

(1) In the comparison result of the compliance calculated from the load-displacement curve on the repeated loading cycles, it was found that the larger the notch to depth ratio are, the energy spent on crack growth of SFRC under the fatigue loading decreases. This phenomenon is true until the first crack occurrence.
(2) According to the S-N curves drawn by the regression analysis on the fatigue test results, the fatigue strength to the first crack static flexural strength decreases by increasing the notch to depth ratio.
(3) Practical formulae for predicting the fatigue strength of SFRC beams with notches are suggested. The fatigue strength with 2,000,000 repeated loading cycles in SFRC beams with the notch to depth ratio varing 0.0, 0.2 and 0.4 shows about 70.1, 65.7 and 60.8% to the first crack static flexural strength, respectively.

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